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A NOTE ON THE DETECTION OF UNDERSEA CRAFT BY MEANS OF LOW FREQUENCY RADIATION FROM AIRCRAFT[1]

BY D. W. R. MCKINLEY[2]

Abstract

A semiquantitative examination is made of the chief factors affecting both the transmission of low frequency radiation from an aircraft to a submarine and the return of this energy to the aircraft by scattering. A general expression is derived for the returning field strength and graphs are shown for a representative set of conditions. It is indicated that, even under the most favourable conditions, the amount of energy returned is below the level of detectability, if the submarine is submerged more than 10 ft. However, it is also pointed out that communication between a shore station and an undersea craft should be feasible under certain conditions.

From time to time the use of low frequency electromagnetic radiation has been proposed for the detection of submarines from aircraft. A study of the attenuation figures for very low frequency radio energy (2) in sea-water tends to encourage this suggestion, which is also supported by reports of undersea reception of long wave land transmitting stations. Interest was renewed recently when some of the undersea craft adopted the breathing device known as Schnörkel, which permitted them to remain submerged at all times. The small target presented by the surfaced part of the Schnörkel tube greatly reduced the range of detectability with methods employing very high frequency radiation. It is the purpose of this note to consider in semi-quantitative detail some of the factors affecting the transmission of electromagnetic energy from the aircraft to the submarine and back to the aircraft.

(a) Free-space Transmission

Consider a source of electromagnetic energy in the aircraft that is radiating P watts uniformly in all directions. By Poynting's theorem the flow of energy across a unit area of a sphere of radius R about the aircraft is proportional to the square of the field strength, E_0, at that point. The flow of energy per unit area is also proportional to $P/4\pi R^2$, so it follows that E_0 is proportional to $\sqrt{P}/R$. The field strength at the distant point may then be written,

$$E_0 = k_1 \frac{\sqrt{P}}{R} . \qquad (1)$$

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In practice, an antenna must be used to radiate the energy, and this antenna will have a gain factor that can be represented by the parameter k_1 for a given direction of transmission. In the absence of any a priori information on the type of antenna system to be used it is not unreasonable to assume (1, 4) the equivalent of a quarter-wave radiator, so that,

$$E_0 \doteq 6000\frac{\sqrt{P}}{R}, \tag{2}$$

where E_0 = field strength in microvolts per metre,
P = power in watts,
R = distance in miles.

An exponential term should be included to allow for attenuation in air but this attenuation is so small by comparison with the factors yet to be considered that it may be neglected.

(b) Attenuation in Sea-water

A portion of the path is through sea-water and for that portion (which shall be assumed to be a small fraction of the total path) the field strength must be multiplied by a factor M (2, 5), where

$$M = e^{-d\sqrt{\frac{\omega\mu\sigma}{2}}},$$

and d = distance traversed in the medium,
$\omega = 2\pi f$, where f = frequency of radiation,
μ = permeability of the medium,
σ = conductivity of the medium,

That is, Equation (2) must now be revised as follows:

$$E_0 = 6000 \cdot \frac{\sqrt{P}}{R} \cdot e^{-d\sqrt{\frac{\omega\mu\sigma}{2}}}. \tag{3}$$

The factor M can be evaluated quantitatively from known experimental information and a parallel development is given herewith from the data available in Stratton's book (5) and Norton's paper (2). Note that Stratton uses m.k.s. units and Norton uses c.g.s. e.m.u.

Stratton

Attenuation factor $M = e^{-Bd}$, where d = distance in medium,

$$B = \sqrt{\frac{\omega\mu\sigma}{2}},$$

$\omega = 2\pi f$, where f = cycles per second,
$\mu = 1.257 \times 10^{-6}$ henry/metre,
$\sigma = 3$ mhos/metre for sea-water,
$(= 3 \times 10^{-11}$ e.m.u. as compared to Norton's 5×10^{-11} e.m.u.)

$$\therefore B = \sqrt{\pi \cdot f \cdot 3 \times 1.257 \times 10^{-6}}$$
$$= 3.42 \times 10^{-3}\sqrt{f} \text{ per metre}$$
$$= 1.05 \times 10^{-3}\sqrt{f} \text{ per foot.}$$

Norton

Attenuation factor $M = e^{-Ad}$, where d = distance in medium,

$$A = \frac{2\pi}{\lambda}\sqrt{\frac{x}{2}}$$

$$x = 1.8 \times 10^{21} \cdot \frac{\sigma}{f}$$

$$\lambda = \frac{c}{f} = \frac{3 \times 10^{10}}{f},$$

$\sigma = 5 \times 10^{-11}$ e.m.u.

$$\therefore A = \frac{2\pi f}{3 \times 10^{10}}\sqrt{\frac{1.8 \times 10^{21} \times 5 \times 10^{-11}}{2f}}$$
$$= 4.5 \times 10^{-5}\sqrt{f} \text{ per cm.}$$
$$= 1.36 \times 10^{-3}\sqrt{f} \text{ per foot.}$$

If M is set arbitrarily at 0.1 then,

$$(1.05 \times 10^{-3})\ (0.434)\ .\ d\ .\ \sqrt{f} = 1,$$

so
$$d = \frac{2200}{\sqrt{f}}\ \text{(Stratton)}, \tag{4}$$

or
$$d = \frac{1700}{\sqrt{f}}\ \text{(Norton)}, \tag{5}$$

where d is in feet and f in c.p.s.

It is clear that the poorer the conductivity of the medium the better the penetration. Stratton has taken a lower experimental value for σ and therefore the depth of penetration for a given frequency is somewhat greater. Stratton's value will be assumed in this note. Graphs of attenuation versus depth for various frequencies are shown in Fig. 1.

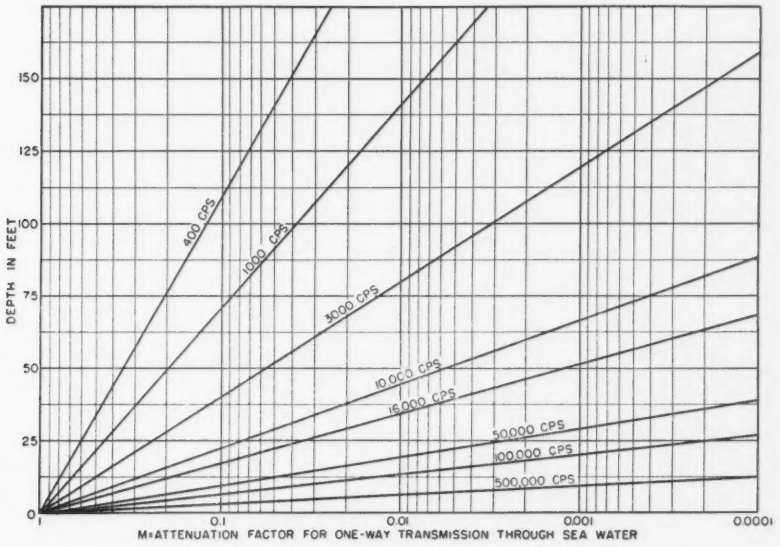

FIG. 1. *Attenuation factor for one-way transmission through sea-water.*

Equation (3) may be rewritten as follows:

$$E_0 = 6000\frac{\sqrt{P}}{R} \cdot e^{-10^{-3}.d.\sqrt{f}}, \tag{6}$$

where $B \doteq 10^{-3}\sqrt{f}$, as above.

(c) Scattering by Object

As seen from Equation (4) the depth of penetration is inversely proportional to the root of the frequency and consequently, to obtain sufficient penetration, it is necessary to use long wave-lengths. When the wave-length used is much longer than the dimensions of the object, specular reflection will not

obtain and the incident radiation will be scattered. The scattering cross-section of a submarine might be difficult to calculate exactly but the following formula (3) will provide an approximate value:

$$\text{Scattering factor} = S = \frac{E_r}{E_0} = \frac{\pi^2}{2} \cdot t^2 \cdot l \tag{7}$$

where E_0 = field strength at the object,

E_r = field strength at the point of observation (here assumed to be at the aircraft),

t = ratio of object diameter (assuming a sphere) to the wave-length, $[t \ll 1]$,

l = ratio of object diameter to distance to the point of observation, $[l \ll 1]$.

Since the velocity of propagation of the electromagnetic waves in water is the velocity in air divided by the square root of the dielectric constant it follows that,

$$\lambda_w = \frac{1}{\sqrt{81}} \cdot \frac{186{,}000}{f} = \frac{2 \times 10^4}{f}, \tag{8}$$

where λ_w is the wave-length in sea-water in miles.

Equation (7) may now be re-written:

$$S = \frac{E_r}{E_0} = \frac{\pi^2}{2} \cdot \frac{D^2}{\lambda_w^2} \cdot \frac{D}{R}$$

$$= 8 \times 10^{-20} \cdot \frac{D^3 \cdot f^2}{R}, \tag{9}$$

where f is in c.p.s.,

D is diameter of object in feet,

R is distance from object to aircraft in miles.

Equation (6) shows the field strength, E_0, at the submerged object (ignoring reflection loss at the air–sea surface). But the field strength, E_r, measured back at the aircraft is now,

$$E_r = E_0 \cdot S = 8.0 \times 10^{-20} \frac{D^3 \cdot f^2}{R} \times 6000 \frac{\sqrt{P}}{R} \cdot e^{-2d \times 10^{-3}\sqrt{f}},$$

or,
$$E_r = 5 \times 10^{-16} \frac{\sqrt{P}}{R^2} \cdot D^3 \cdot f^2 \cdot e^{-2d \times 10^{-3}\sqrt{f}}. \tag{10}$$

It will be noticed that the attenuation term is now squared to take into account the water attenuation on the return passage.

(d) Reflection from Surface of Water

Fig. 94, page 509 of Stratton's book (5), shows graphs of reflection coefficients of electromagnetic waves at an air–sea surface for frequencies less than 10^6 c.p.s. At normal incidence the reflection coefficient is 83%, and the transmission coefficient, 17%, for either horizontally or vertically polarized

radiation. The transmission factor, T, of the return radiation will also be 17%, so the two-way transmission factor T^2 will be $(0.17)^2$ or 0.03, and Equation (10) should be multiplied by this factor for normal incidence.

As the angle of the incident radiation deviates further from the normal it will be seen that the transmission factor for *vertically* polarized waves increases to a maximum of about 83% at approximately 4° inclination to the horizontal. The two-way transmission factor is now $(0.83)^2$ or 0.7, but this increase is counterbalanced by the fact that the distance to the submerged object is now given by $R_1 = \frac{R}{\sin 4°} = 14 \cdot R$ in air. There is a slight increase in the water-path to the object as well but this is small owing to the high effective index of refraction. Even for the extreme case where the incident radiation is grazing the surface, the angle of refraction is $\sin^{-1}\frac{1}{\sqrt{81}}$, so that the water-path is increased by only 11%. An inspection of Equation (10) with the inclusion of the air–sea transmission factor shows that, although at the most favourable angle for penetration the two-way transmission factor is $0.7/0.03 = 23$ times as great as for normal incidence, the received field strength, for a given height of aircraft, must now be divided by $(14)^2$. It is evident, then, that the maximum return occurs for an object directly beneath the aircraft. Therefore, a two-way transmission factor of 0.03 will be taken as representing the most favourable condition.

The expression for the returning field strength at the aircraft is now,

$$E_r = 1.5 \times 10^{-17}\frac{\sqrt{P}}{R^2} \cdot D^3 \cdot f^2 \cdot e^{-2d \times 10^{-3}\sqrt{f}}. \tag{11}$$

On inspection it is apparent that there should be an optimum frequency for maximum field strength, if the other parameters remain constant.

Let $a = 1.5 \times 10^{-17}\frac{\sqrt{P}}{R^2} \cdot D^3$ and $b = 2d \times 10^{-3}$,

Then $E_r = a \cdot f^2 \cdot e^{-b\sqrt{f}}$

$$\frac{dE_r}{df} = a \cdot e^{-b\sqrt{f}}\left(2f - \frac{bf^2}{2\sqrt{f}}\right),$$

and to maximize E_r it follows that

$$f_{opt} = \frac{16}{b^2} = \frac{4 \times 10^6}{d^2}, \tag{12}$$

where f_{opt} is in cycles per second and d is the depth in feet. (Note that Equation (12) and Equation (4) have the same form—that they are nearly identical numerically is purely coincidental, since Equation (4) was developed for the arbitrary value $M = 0.1$ and the constant would be quite different for any other value.)

A graph of f_{opt} versus depth is shown in Fig. 2.

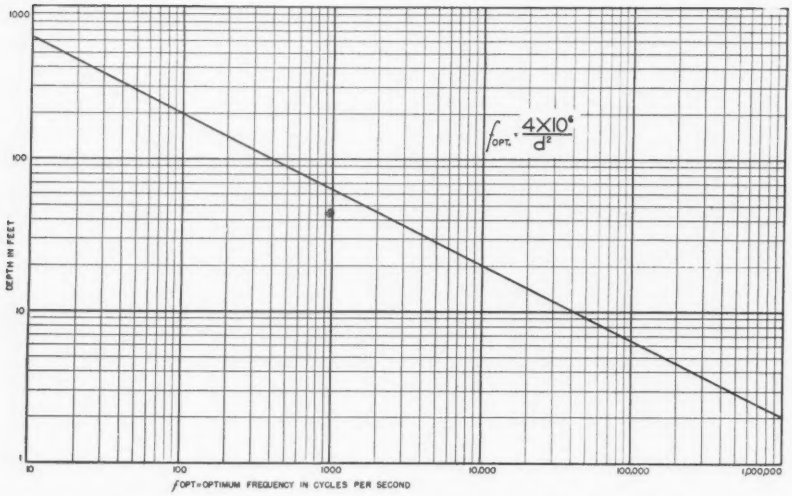

FIG. 2. *Optimum frequency of radiation for a given depth of penetration.*

The value of f_{opt} given by Equation (12) is now inserted in Equation (11) (it is noted that the exponential term becomes $e^{-4} = 0.018$) and the expression reduces to

$$E_{r_{max}} = 4 \times 10^{-6} \frac{\sqrt{P}}{R^2} \cdot \frac{D^3}{d^4} \tag{13}$$

where $E_{r_{max}}$ is the maximum field strength received at the aircraft in microvolts per metre, provided the optimum frequency is used,

P is the *radiated* power in watts (which may be only a small fraction of the generator power),

R is the distance from the aircraft to the undersea craft in miles,

D is the diameter of the undersea object in feet,

d is the depth of the undersea object in feet.

It is now necessary to estimate the effective scattering diameter of a submarine. It seems not unreasonable to assume that a metallic sphere 100 ft. in diameter would scatter at least as much radiation as a representative submarine and probably more on the average if one considers the random orientation of the needle-shaped submarine in the electromagnetic field. Some typical graphs of depth versus maximum received signal strength are shown in Fig. 3, for the case where $D = 100$ ft. Caution should be used in applying the formula for small values of R because the approximations become less and less permissible. Also, the induction field becomes the predominant factor for $R < \frac{\lambda}{2\pi}$. However, with reservations, it is possible

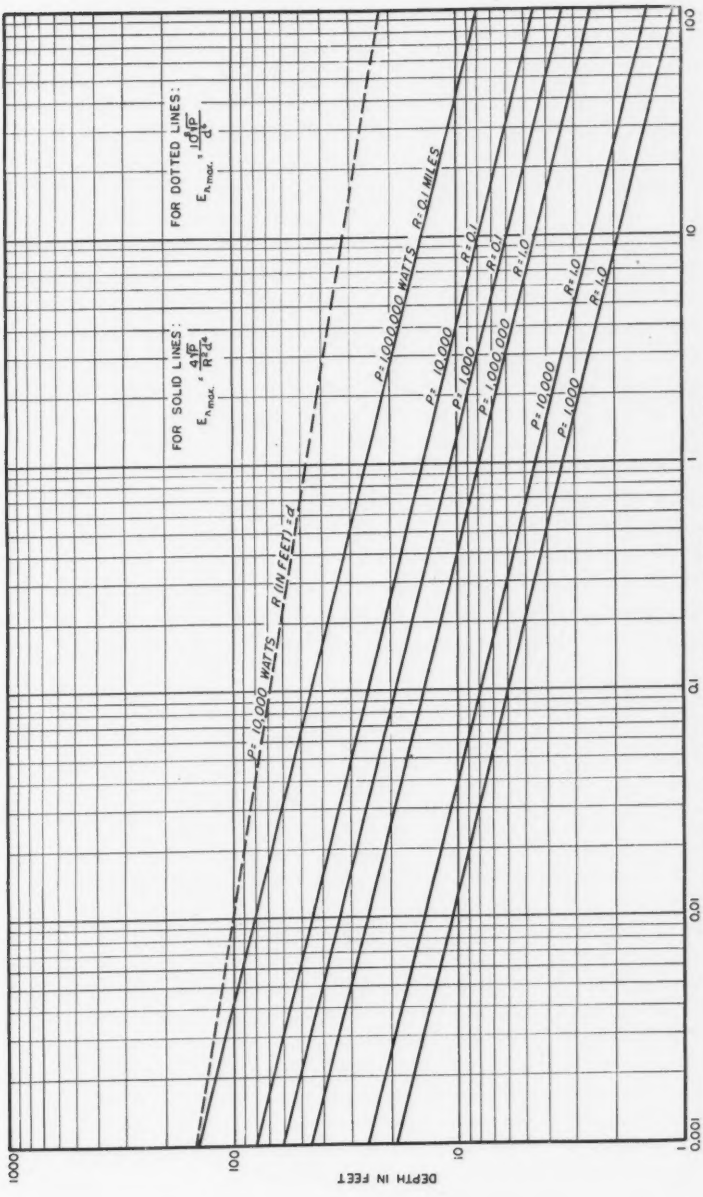
FOR SOLID LINES: $E_{h\,max.} = \frac{4\sqrt{P}}{R^2 d^4}$
FOR DOTTED LINES: $E_{h\,max.} = \frac{10\sqrt{P}}{d^4}$
P = 10,000 WATTS R IN FEET
P = 1,000,000 WATTS R = 0.1 MILES
P = 10,000 R = 0.1
P = 1,000 R = 0.1
P = 1,000,000 R = 0.1
P = 10,000 R = 1.0
P = 1,000 R = 1.0
1000
100
10
1
0.1
0.01
0.001
DEPTH IN FEET
$E_{h\,max.}$ = MAXIMUM RECEIVED FIELD STRENGTH IN MICROVOLTS PER METER

FIG. 3. *Maximum received field strengths obtainable under representative conditions, assuming use of optimum frequency.*

to use Equation (13), or the particular cases of this equation that are shown graphically in Fig. 3, to demonstrate that the detection of undersea craft through the use of electromagnetic radiation is not practical. (The dotted line shown in Fig. 3 is for a limiting case where $R = d$, and the aircraft is at the surface of the water. This case is here of passing interest only, because the conditions for the approximations are thoroughly violated.)

Practical Considerations Involved in the Detection of Submarines by Radiation Methods

The generation of 1,000,000 watts of power at these frequencies by means of airborne equipment is out of the question with available techniques. Pulse methods, which do enable peak powers of this order to be generated at high frequencies, are not practical in this case because one cycle of radiation, provided that a single cycle pulse could be produced, would be 100 microseconds in duration at a frequency of 10,000 c.p.s., and the transmitting tube capacity required for pulses of this length is not much less than that required for the generation of continuous waves. Practical experience suggests that several cycles are required to form a coherent pulse. In any case, the pulse is so long that no detection resolution is possible. Continuous wave, frequency modulation, phase, or Doppler detection technique, offer only slightly more hope for the detection of undersea craft than the pulse method. But here again the phase change is very small, and if a Doppler method is used, one has the problem of "bucking out" the large transmitter power in order to detect a signal that may be 160 db. weaker and on the same frequency.

Whether vacuum tubes or high speed alternators are employed it is unlikely that the airborne equipment could generate more than 10,000 watts. The problem of radiating this low frequency power efficiently from an airborne transmitting antenna is difficult indeed, and the actual power radiated will be considerably less than the output of the generator.

The atmospheric noise levels are higher at these low frequencies than at the very high frequencies. The minimum signal strength required to produce a detectable signal will depend on this noise level, and also on the receiver bandwidth, which would have to be designed to accommodate the particular detection technique employed. It is probable that 10 μv. per metre represents the average minimum detectable signal. From Fig. 3 it is immediately apparent that the ordinate at $E_r = 10$ μv. per metre shows a maximum depth for detection of about eight feet for any of the reasonable combinations of powers and distances given. Furthermore, a frequency of 60,000 c.p.s. must be used; any higher or lower value will result in less field strength. This, of course, is only an example taken at random, but a consideration of Equation (13) in the light of the above remarks should yield convincing proof that there is a very poor prospect of success in attempting to apply electromagnetic radiation techniques to the detection of submarines from aircraft. Nor should the methods be considered for shipborne use because

the present supersonic techniques afford much greater range and in addition provide distance resolution and directivity.

It should be emphasized that the foregoing remarks apply to the detection of undersea objects by *radiation* methods only. As was suggested above, at close ranges the *magnetic* (or *induction*) field assumes importance, and in fact a fair degree of success can be obtained by the application of standard and well established geophysical techniques, involving the detection from very low flying aircraft of the distortion produced in the earth's magnetic field by a ferrous object such as a submarine.

In passing, it may be noted that one-way transmission of intelligence from a land station to an undersea craft or vice versa is possible. For example, let us assume that a land transmitting station is radiating 500,000 watts on a frequency of 16,000 c.p.s. (e.g., Rugby, England). Suppose the submarine is 1000 miles distant and that the radiation (which should be *vertically* polarized!) enters the water at about the optimum angle of incidence of 86°, with a corresponding transmission factor of 0.8. If the submarine is at a depth of 17 ft. the attenuation factor, as read from Fig. 1, is 0.1. Therefore, the field strength at the submarine is, approximately,

$$E_0 = 6000 \frac{\sqrt{500{,}000}}{1000} \times 0.1 \times 0.8$$

$$= 350 \ \mu\text{v. per metre.}$$

While this is a very rough estimate of field strength it does demonstrate that the received field strengths to be expected with one-way transmission are well above threshold detectability, even at long distances.

References

1. EVERITT, W. L. Communication engineering. 2nd ed. McGraw-Hill Book Company, New York and London. 1941.
2. NORTON, K. A. Ground wave propagation. Federal Communications Commission. 1941.
3. OLLENDORFF, F. Elek. Nachr. Tech. 8 : 147-161. 1931.
4. SOMMERFELD, A. Ann. Physik, 28 : 665-736. 1909.
5. STRATTON, J. A. Electromagnetic theory. McGraw-Hill Book Company, New York and London. 1941.

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